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THE ABRASION CHARACTERISTICS OF CERTAIN PROTECTIVE COATINGS ON ALUMINUM AND MAGNESIUM ALLOYS

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The abrasion resistances of two finishing systems, one applied to 2014 aluminum and the other to ZK60A magnesium, were evaluated. Both alloys were first anodized. Subsequently, a blue-wash primer and semigloss paint were applied to the 2014 aluminum; the ZK60A magnesium received a polyamide primer and a polyurethane topcoat. The tests, performed to compare the relative abrasion resistances of the two systems, were carried out using the Taber Abraser Model 503. Abrasion rates were measured by a weight-loss technique.
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Analysis of the data indicated that, under the test conditions applied, the topcoats contributed little to the overall abrasion resistance of the two coating systems; rather, the anodic layer of each appeared to be the most important parameter. Further, the rate of abrasion of the anodic layer was relatively constant in each case and could be approximated by a straight line relationship. The anodic film on the 2014 aluminum demonstrated significantly better resistance to abrasion than that on the ZK60A magnesium.

TABLE OF CONTENTS

	Page
Introduction	1
Objective	2
Procedure	2
Results and Discussion	4
Conclusions	6
References	7

LIST OF TABLES

1. Abrasion Rate - Medium Abrader	8
2. Abrasion Rate - Heavy Abrader	9

LIST OF FIGURES

1. Taber Abraser Model 503	10
2. Typical Wear Track on Test Specimens	10
3. Typical Abrasion Curve - Aluminum	11
4. Typical Abrasion Curve - Magnesium	12
5. Layers in 2014 Aluminum Film	13
6. Layers in ZK60A Magnesium Film	13

INTRODUCTION

Lightweight, nonferrous alloys are frequently used in structural applications to utilize their high strength-to-weight ratios. In particular, aluminum and magnesium alloys are widely used for this purpose. There are presently several alloys in each system that demonstrate adequate strength and ductility for certain low-medium strength weapon applications.

The magnesium (Mg) alloys have significantly lower densities than the aluminum (Al) alloys and are, therefore, very attractive. However, a serious drawback to the utilization of the Mg alloys is their susceptibility to corrosion and stress corrosion[1,2,3]. This problem is dealt with by protectively coating the Mg alloys, especially in critical applications, by anodizing and painting. The corrosion resistance of various finishing systems on Mg has been investigated by Sandler[4,5] and Brown[6]. One system that displayed excellent corrosion resistance was a combination of DOW-17 anodize (MIL-M-45202) with epoxy polyamide primer (MIL-P-23377) and polyurethane topcoat (MIL-C-81773). Anodized and painted aluminum alloys have also been found to be highly resistant to corrosion[5].

In service, however, the corrosion resistance of a protective finishing system is not the only important criterion; the abrasion resistance of the coating must also be considered because, as the thickness of the "film" diminishes through wear, its protective abilities also decrease. The best corrosion-resistant coating system

can be rendered ineffective if it exhibits poor resistance to abrasion.

OBJECTIVE

The purpose of this study was to evaluate the abrasion characteristics, both qualitatively and quantitatively, of two specific finishing systems, one applied to an aluminum alloy and the other to a magnesium alloy. The two systems were similar in that they both contained an anodic layer, whereas the topcoats were somewhat dissimilar. Abrasion information of this nature will assist in predicting the useful service life of components that are manufactured from the respective alloys and receive these coating systems.

PROCEDURE

Test specimens, 102mm x 102mm x 1.6mm (4" x 4" x 1/16") were prepared from 2014 aluminum alloy and ZK60A magnesium alloy stock. These plates were machined and ground to dimension. The finishing systems were applied as follows:

A. Anodizing - The aluminum alloy specimens were anodized by the sulphuric acid process per ASTM Standard B580, while the DOW-17 process was used to anodize the ZK60A specimens per MIL-M-45202.

B. Priming - The anodized specimens were immediately primed; the 2014 plates received a blue wash primer per MIL-P-15328C and the ZK60A plates were coated with epoxy-polyamide per MIL-P-23377.

C. Painting - The 2014 plates were sprayed with a semigloss enamel paint (Federal Specification TT-E-485F); the ZK60A specimens were given a polyurethane topcoat (MIL-C-81773).

The finished specimens were tested on a Taber Abraser Model 503 (Figure 1) utilizing both the CS-10 and H-10 wheels at a constant load of 500 grams. The CS-10 Calibrase, a resilient, medium abrasive, wheel is designed to simulate the mild abrasion experienced in normal handling, cleaning, and polishing. The H-10 Calibrase, a non-resilient, vitrified wheel, is a much harsher abrasive. The rate of abrasion was determined by the weight loss technique. The weight (w) of each specimen was initially recorded and then measured periodically throughout the test. This data was plotted versus the respective number of cycles. The slope of the curve (dw/dN) at any point is the instantaneous rate of abrasion, while the average slope of the curve over the period of a particular layer, e.g., anodic film, was considered to be the abrasion rate in that layer.

Testing was continued until a significant breakthrough to the base metal was visually observed. Also, breakthroughs to the primer and anodic film were recorded. As the data will show, the section of the curves corresponding to the abrasion of the anodic film fits a straight line relationship. Therefore, this portion of the data was subjected to a linear regression analysis and the slope, intercept and correlation coefficient were calculated for each specimen.

This type of behavior, i.e., relatively constant wear resistance, has been previously recognized in anodized aluminum[7].

RESULTS AND DISCUSSION

During testing, the topcoats (paint and primer considered together) were worn away in relatively few cycles and contributed little to the overall abrasion resistance of the coatings. Rather, the abrasion characteristics of the anodic layers was the important parameter. A wear track, illustrative of those formed on the tested specimens, is shown in Figure 2. Typical abrasion curves for the two systems are illustrated in Figures 3 and 4.

For a particular set of conditions (load and abrader) the anodic film on the 2014 aluminum alloy exhibited significantly better abrasion resistance than that on the ZK60A magnesium alloy. No doubt, this behavior is associated with the fact that aluminum oxide is considerably harder than magnesium oxide. Other investigators have reported abrasive wear to be roughly proportional to the hardness of the abraded material[8-10].

The abrasion rates for the anodic layers, as determined by the linear regression analysis, are given in Tables 1 and 2. As shown, the anodized magnesium abrades at 11.2 micrograms per cycle or approximately 11 times the rate of the anodized aluminum under the "medium abrasive" conditions, while it abrades at 67.2 micrograms per cycle or about 4 times the rate of the anodized aluminum for the "heavy abrasive"

condition. As was expected, the rate of abrasion of the two anodic films increased with the severity of the abrasive surface. However, the increase in abrasion rate was not proportioned; the wear rate of aluminum increased significantly more than that of the magnesium under the "heavy abrasive" condition. Perhaps this anomalous behavior can be attributed to the clogging of the H-10 wheels with the material being abraded. Abrasion would then result not only from the wheel, but also from the oxide being picked up. Alumina is the harder of the two oxides, so it is therefore likely that the abrasive effect of alumina on itself was greater than the self-abrasion of the magnesia. This phenomenon was not as serious a problem when using the CS-10 wheels as equipment was available to dress the wheels periodically.

The anodic film formed on the 2014 aluminum was evidently more uniform in composition than the magnesium anodized film. This was observed by noting color changes in the films during abrasive testing and by cross-sectional examination of the respective coatings (Figures 5 and 6). The anodized magnesium contained two distinct layers of different hardness which could have contributed to the slightly poorer straight line fit of the magnesia than the alumina as evidenced by the R (correlation coefficient) values (Tables 1 and 2). Nevertheless, the R values do indicate that the straight-line approximation is valid for both the alumina and magnesia and that their abrasion behavior can be expressed as the slopes of these lines.

It should be emphasized that the accuracy of this approach to measuring abrasion rates in protective coatings depends somewhat on the judgment and interpretation of the investigator. Specifically, determination of the "breakthrough" point between the various layers is quite subjective. Also, the operator must decide how often to reface the abrasive wheels in order to obtain reliable abrasion data with a minimum of scatter.

An alternative to the weight-loss technique would be a measurement of the change in thickness of the coating periodically during cycling. The film thickness on ferromagnetic materials can be measured by magnetic methods (viz Nordson Film Gauge); an eddy-current type device can be used for similar determinations on nonferrous materials.

CONCLUSIONS

Based on the results obtained in this investigation, the following conclusions are permitted:

1. The topcoat layers of primer and paint do not play a significant role in the abrasion resistance of these coatings.

2. The abrasion rate of the anodized aluminum was considerably lower than the rate of anodized magnesium for the same load and abrader.

3. The abrasion rate of the anodic film, on both Al and Mg as determined by the weight loss technique, can be expressed as the slope of the straight line portion of the abrasion curve (weight vs cycles), corresponding to the anodic region.

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TABLE 1. ABRASION RATE - MEDIUM ABRADER

ALUMINUM

Specimen	dw/dN (micrograms/cycle)	R
1	1.45	.992
2A	0.73	.996
2B	1.07	.990
Average	1.08 ± 0.36	

MAGNESIUM

Specimen	dw/dN (micrograms/cycle)	R
1A	12.3	.991
1B	11.6	.989
2A	10.7	.988
3A	10.2	.983
Average	11.2 ± .93	

CS-10 WHEELS
500 GRAM LOAD
R - Correlation Coefficient
Straight Line Regression

TABLE 2. ABRASION RATE - HEAVY ABRADER

ALUMINUM

Specimen	dw/dN (micrograms/cycle)	R
3A	10.9	.995
3B	18.1	.997
5	19.1	.998
Average	16.0 ± 4.47	

MAGNESIUM

Specimen	dw/dN (micrograms/cycle)	R
4A	65.7	.998
5	68.3	.987
6	67.6	.984
Average	67.2 ± 1.35	

H-10 WHEELS
500 GRAM LOAD

R - Correlation Coefficient
Straight Line Regression

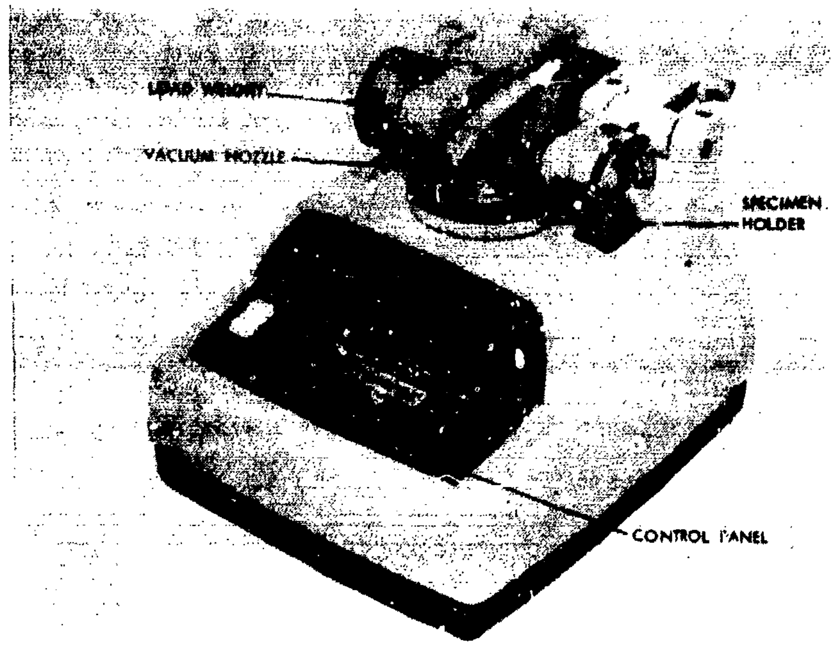

Figure 1. Taber Abraser Model 503.

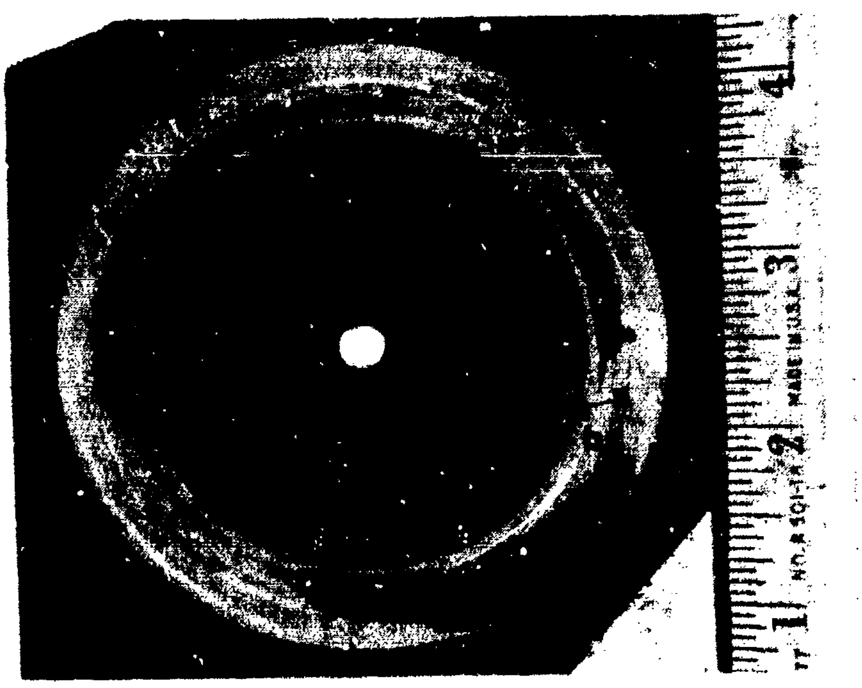

Figure 2. Typical wear track of test specimen (1 Al).
a. [illegible]
b. Anodic film
c. Base metal.

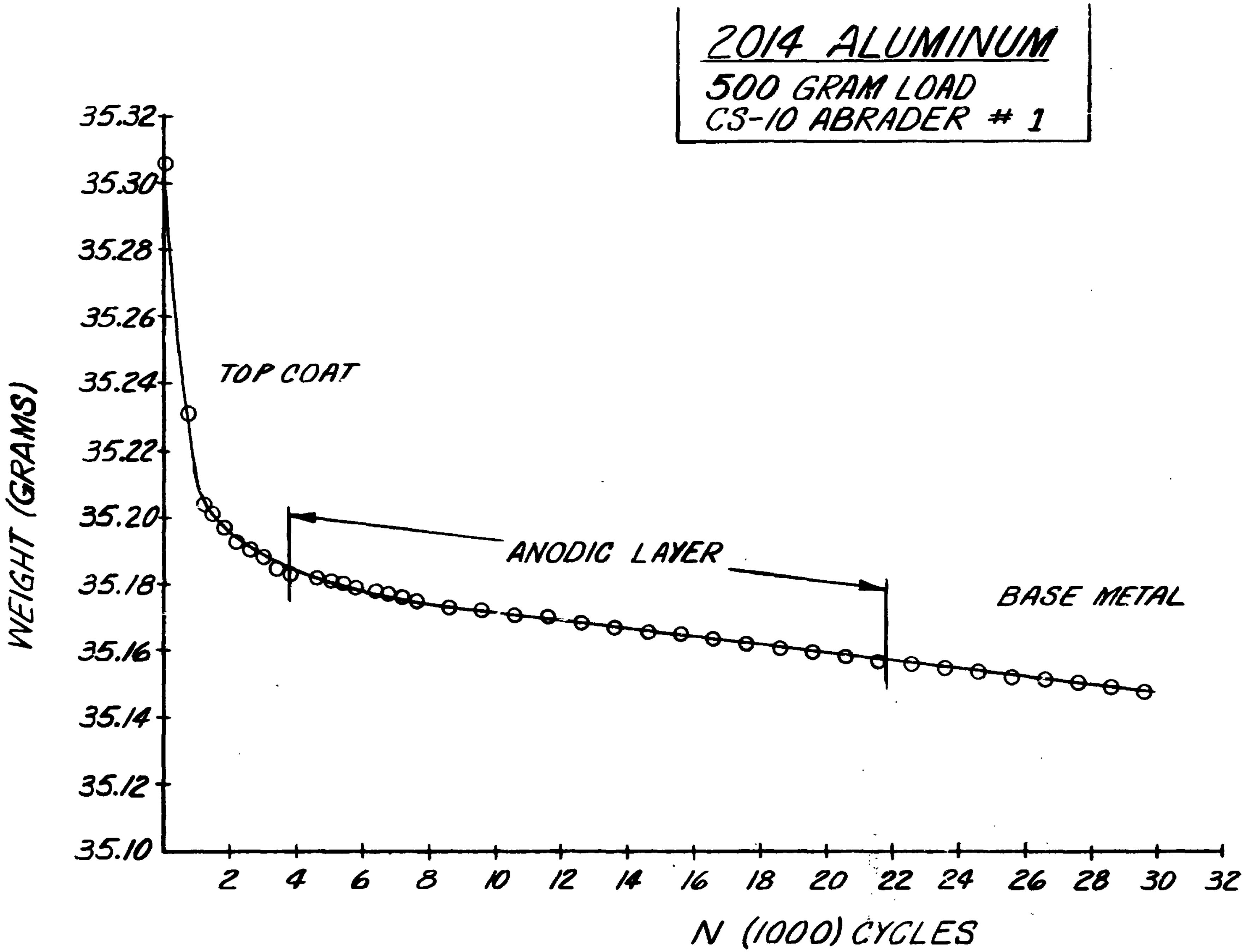

Figure 3. Typical abrasion curve - aluminum.

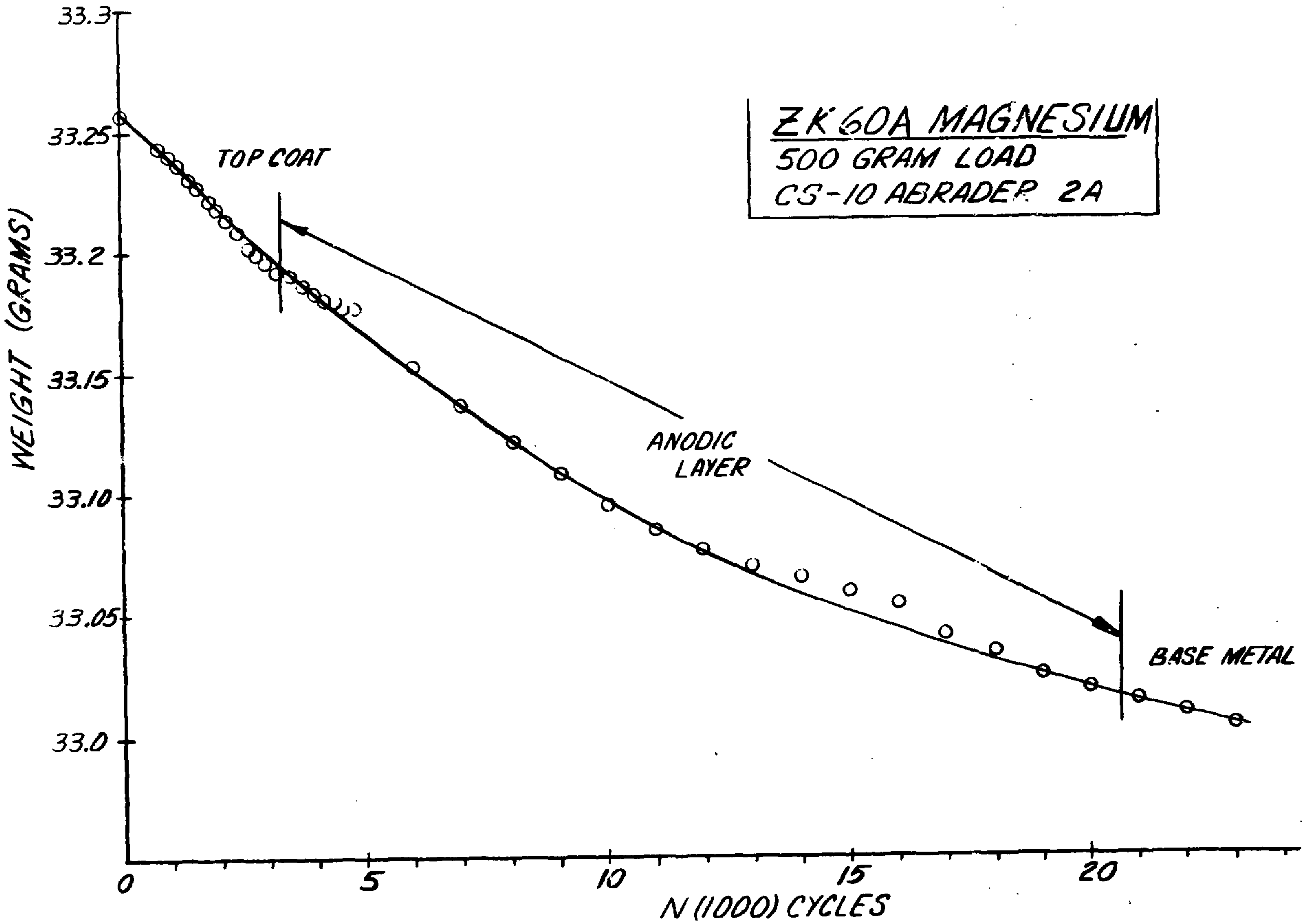

Figure 4. Typical abrasion curve - magnesium.

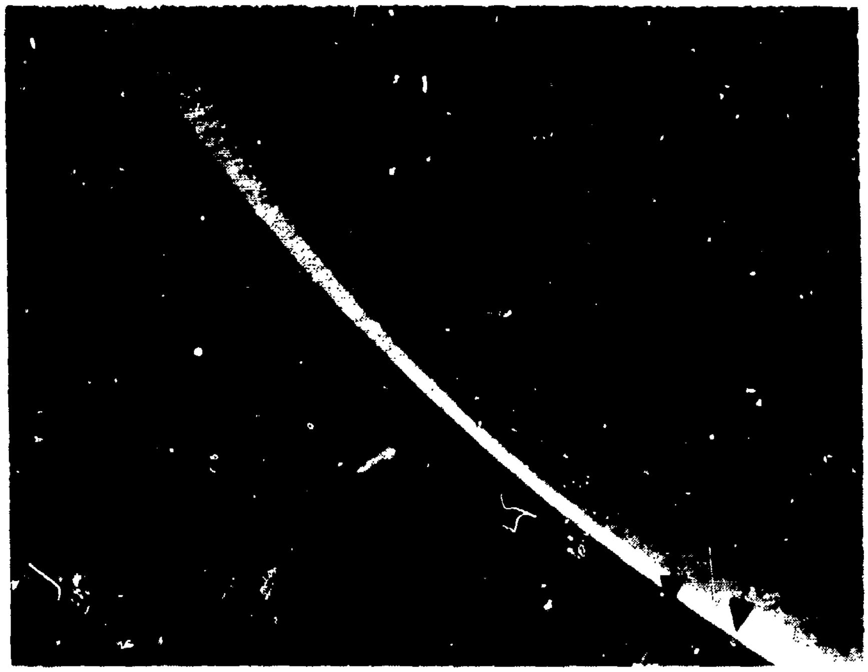

Figure 5. Layers in 2014 aluminum film.
a. Paint
b. Primer
c. Anodic layer
d. Base metal

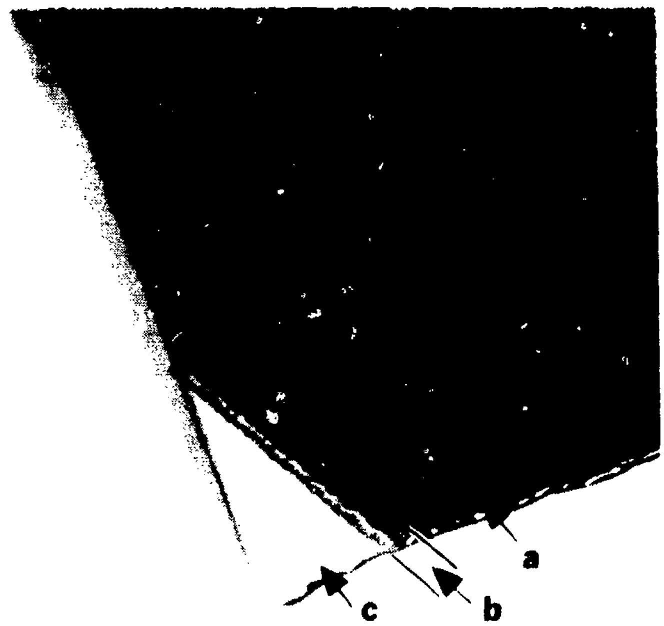

Figure 6. Layers in ZK60A magnesium film.
a. Topcoat
b. Anodic film showing several layers
c. Base metal

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